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The great capricorn beetle *Cerambyx cerdo* L. in south-western Poland – the current state and perspectives of conservation in one of the recent distribution centres in Central Europe

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Abstract

Presence-only models can aid conservation and management of threatened, elusive species. A MaxEnt model has been developed for the great capricorn beetle (*Cerambyx cerdo* L., 1758) in south-western Poland and the variables identified best explaining the species' occurrence on a large scale. Once successfully validated, the model was used to (a) illustrate the expected location of the species' habitats in the region and in existing Natura 2000 sites (SACs) in S-W Poland and (b) assess the efficacy of the regional network of national protected areas (NPAs) *versus* Natura 2000 (SACs). Overall, information was gathered on 1025 localities of *C. cerdo* L., 1758 in Lower Silesia. All the records came from the pedunculate oak *Quercus robur* L., 1753. The occurrence of the great capricorn beetle in the study region is limited mainly to its eastern part, with a marked concentration in the valleys of the rivers Odra, Barycz and Bystrzyca. The kernel density estimation analysis also showed the high concentration of occupied trees in the north-western part of the region, clearly isolated from the above-mentioned main populations. Although a considerable part of the localities in the study region (74.2%) occurred within protected areas (PAs), their contribution to the species' conservation varied between the PAs groups. Natura 2000 SACs are the most important PAs, covering more than 30% of

the predicted area of suitable habitats in the region and more than 45% of optimal habitats. In total, 384 localities of *C. cerdo* L., 1758 were found within the cities, most of them (n = 356) in the city of Wrocław. Forty three percent (43%) of the urban localities of the species (n = 165) in the study region are protected within the regional network of protected areas (OPAs), while those unprotected are mainly concentrated in the city of Wrocław (n = 207). Wrocław also includes 17.1% of the area of suitable habitats and 29% optimal habitats of the species in the region outside the protected area network. To preserve *C. cerdo* L., 1758, forest corridors should be created or restored to bridge the otherwise impermeable gaps revealed by the authors' model and grant protection to the still largely unprotected area of the Lower Silesian territory. The species conservation programme in the region requires the cooperation of various authorities, not only those dealing with nature conservation, but also local governments, state forest management and flood protection authorities.

Keywords
Conservation, saproxylic beetles, long-horn beetle, NATURA 2000, *Quercus*, Lower Silesia

Introduction

The great capricorn beetle (*Cerambyx cerdo* L., 1758) is the largest longhorn (Cerambycidae) beetle in Poland and one of the largest beetle species in Europe. Since fairly recently, the species has been under strict legal protection, not only in Poland, but also in most other European countries. It is included in Annex II of the Bern Convention (Convention on Conservation of Species 1979) and in Annexes II and IV of the EU Habitats Directive (Council of the European Communities 1992). Its high conservation status results from the global shrinking of its range which has been observed for more than 100 years (Buse et al. 2007) and resulted in its placement on the IUCN world's list of endangered species, with VU category (IUCN 2017). It should be emphasised that the populations from the north and centre of the continent are the most endangered. For example, in comparison with southern populations, the species has become extinct in Belgium, the Netherlands, Luxemburg, Great Britain, European part of Russia and in Latvia (Alexander 2002, Hedin 2014, Huijbregts 2003, Alekseev 2007, Barševskis and Avgin 2014, Volkova 2015). In Sweden, one population has survived out of the four that were known in the early 20th century; it is located in the nature reserve of Halltrop on the island of Öland (Lindhe et al. 2010, Hedin 2014). The species' decline has also been observed in the Czech Republic, Slovakia and northern Germany (Sláma 1998, Ellwanger 2009, Drag and Cižek 2015). In Poland, as in the adjacent countries, *C. cerdo* L., 1758 has markedly declined and today, its occurrence is limited to the areas west of the Vistula River, with the concentration of sites in the western (Rogalin Warta Valley) and south-western (valleys of the Odra, Barycz, Widawa, the city of Wrocław) parts of the country (Pawłowski et al. 2002, Gutowski 2004, Starzyk 2004, Bunalski 2012, Stachowiak 2012). The above authors regard the population from south-western Poland as the strongest and, in terms of the occupied in area, largest in the country and, as shown by the data from the adjacent countries, also in the region. An interesting and, at the same time, disturbing fact is the lack of recent data on the occurrence of the great capricorn beetle in well preserved forest

complexes of the north-eastern part of Poland, for example Białowieża Forest. For this reason, despite the existence of numerous populations in southern Europe and North Africa where locally (Morocco, Algeria and Mallorca, Spain), the great capricorn beetle is reported as a pest of oak woods (e.g. Chakali et al. 2002, González et al. 2010, El Boukhari et al. 2015, Torres-Vila 2017, Torres-Vila et al. 2017), the state of preservation of the species in the Atlantic and continental biogeographical regions is regarded as poor (U2; Ellwanger 2009). This phenomenon results mainly from habitat destruction (natural disappearance or felling of old, ancient deciduous trees in forests, parks, roadsides and on flood banks) with a simultaneous absence of natural or artificial oak regeneration. Another probable reason for the species' disappearance in Poland may also be the decreasing levels of groundwater which affects the condition of trees inhabited by *C. cerdo* L., 1758 (Jankowski and Świerkosz 1995). Some authors also point to modern forest management as the reason for the species' disappearance in that part of the range which favours thick, fast-growing and shaded forests at the expense of the earlier, light and sparse tree stands. The consequences of the reduced area of adequate habitats include fragmentation and isolation of individual populations, most of them having a patchy character (Stachowiak 2012). In Poland, only populations in the valleys of Barycz and Odra seem to be sufficiently extensive and connected by semi-natural ecological corridors, formed by forests or linear tree stands in open landscape (e.g. tree rows along roads or on flood banks; single oaks on floodplain meadows).

As mentioned above, adults of *C. cerdo* L., 1758 are noticeably large, with body length up to 60 mm. Additionally, the beetle seems to be even larger due to its extremely long antennae which, in males, can be twice as long as the body. Its imposing larvae, which can be longer than adults (up to 100 mm), are xylophagous on different oaks, rarely on other tree species (e.g. Luce 1997, Sláma 1998, Neumann and Malchau 2010, Torres-Vila et al. 2017, Oleksa and Klejdysz 2017). Adults are observed from late spring to summer, chiefly at dusk and in the evening. Considering these facts, the best detection method is searching for fresh signs of larval activity on trunks or branches i.e. wide and long galleries or characteristic holes with a red interior. Due to the beetle size and the poor quality of its food, the larval development takes place over a period from 3 to 5 years. According to recent studies, the species prefers trees with sun-exposed trunk, diameter more than 60 cm, thick bark and presence of sap exudation (Buse et al. 2008, Albert et al. 2012, Oleksa and Klejdysz 2017). Despite the generally small dispersal and sedentary behaviour, some adults cover distances exceeding 1000 m, with maximum rates of even 400 m/day (Torres-Vila et al. 2017).

The EU regulations on creating the ecological network Natura 2000, in force in Poland since 2004, have stimulated the interest in the great capricorn beetle in this part of Europe. The requirements imposed then on Poland and pertaining to designation and establishment of areas Natura 2000 and the consequent natural history inventories, have contributed to a better knowledge of the species in various regions of the country. Most of the records from Poland, including its south-western part, date from the boundary of the 19^{th} and 20^{th} century (for review, see Burakowski et al. 1990). They are thus historic records and, in many cases, imprecise.

The objective of this paper is to update the knowledge on the distribution of the great capricorn beetle in Lower Silesia as one of the last large refuges of the species, not only on a regional and country-wide scale, but also in Central Europe. The data, combined with climate-habitat variables, were used to create a model based on the algorithm MaxEnt in order to specify: 1) factors which affect the occurrence/distribution of the species in the studied area; 2) present state of habitat fragmentation and areas which are crucial for the species' protection, considering the "conflicting" areas where the protection may be rendered difficult, for example, urban areas and to propose a strategy for effective conservation and identification of the most important threats and 3) assess adequacy/efficacy of the previous and present nature conservation systems in the context of the species' preservation in the region.

Regarding the last-mentioned goal, the species is interesting in that, in Poland, it has been under legal protection since 1952 (!) and thus offers a unique opportunity to evaluate the two systems – the one based on nature reserves and landscape or national parks and the one based on habitat protection areas, especially considering that Natura 2000 is subject to criticism not only by that part of the community not interested in nature conservation, but also by naturalists and scientists (Cardoso 2012, D' Amen et al. 2013, Hochkirch et al. 2013).

Methods

Study area

The study region, covering the north-east part of the Lower Silesian province (approx. 9,571 km^2), is located in south-western Poland. The altitude ranges from 60 to 703 m above sea level (mean 134 m a.s.l.). The climate is temperate with an average annual rainfall of about 600 mm. According to Corine Land Cover maps (CLC2006; available from: http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version), the region is dominated by agriculture (~65% of the total area), especially arable land (53.4%). Forests cover 25% of the total area, of which 54% are coniferous forests, 19.4% broad-leaved forests and the remaining 26.6% – mixed forests. Urban areas (class 1.1 in CLC) cover 5% of the total area.

Nationally designated protected areas (NPAs) are represented by 32 nature reserves and 4 landscape parks with a total surface of approx. 81 km^2 (0.8% of the region) and 1,014 km^2 (7.3%), respectively. In total, the NPAs cover a surface area of 1,021 km^2. The Natura 2000 network consists of 39 sites, including 8 Special Protection Areas (SPAs) designated under the Birds Directive (total area of 863 km^2 in the region) and 31 Special Areas of Conservation (SACs) under the Habitats Directive (total area of 1,213 km^2). All the stand-alone SPA sites were excluded from these analyses as they are only aimed at protecting bird species, while the SACs were included, increasing the total protected surface in the study region by 451 km^2. In total, the overall protected areas (OPAs) cover an area of 1,472 km^2 (15% of the region).

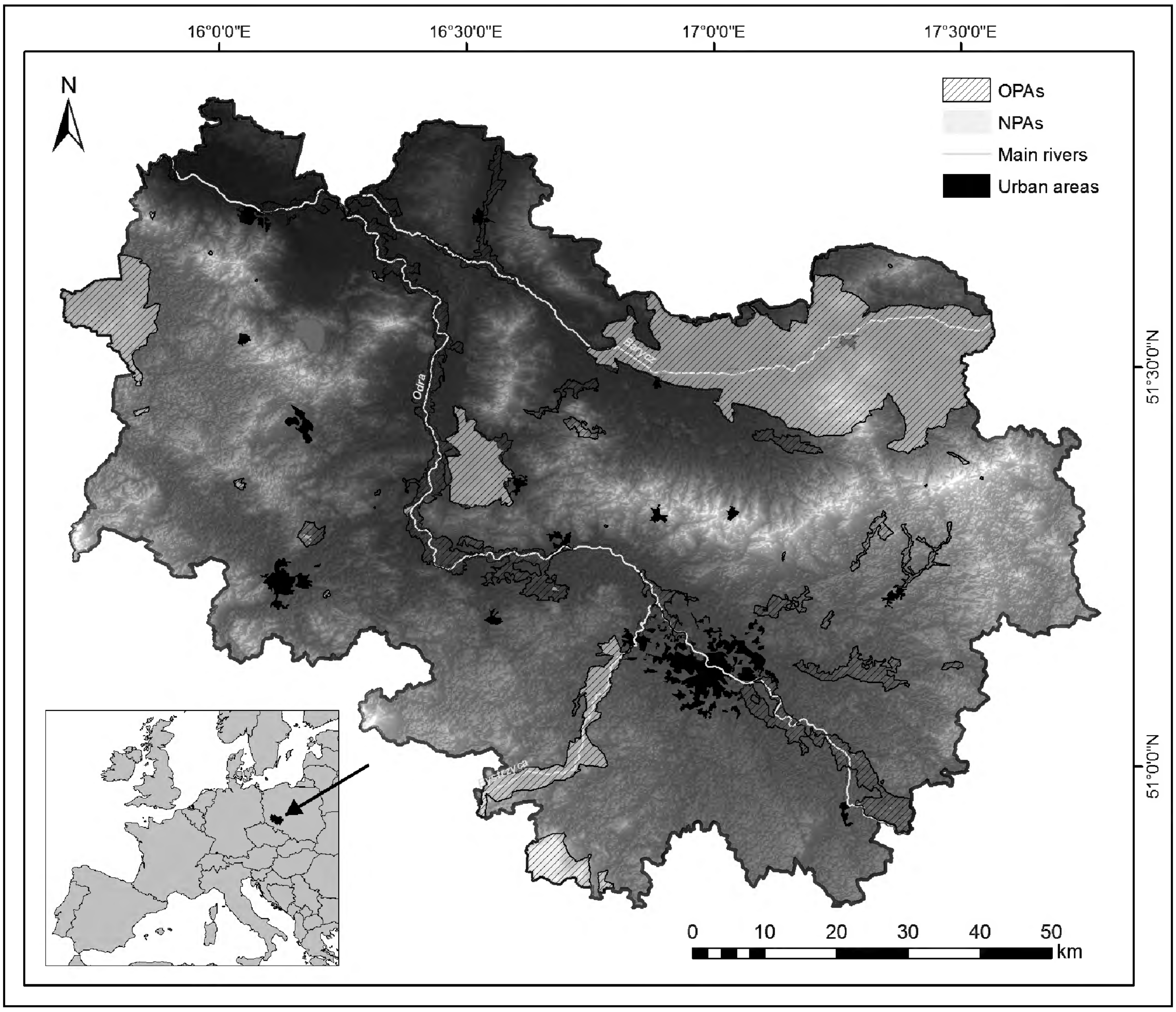

Figure 1. Study region with the network of nationally protected areas (NPAs) and overall protected areas (OPAs).

Field surveys

The data used on the occurrence of the species was collected in 2001–2013 by the staff, co-workers and volunteers of the Laboratory of Invertebrate Conservation Biology and Protection, Wrocław University. Each tree with signs of occupancy by the beetle's larvae such as holes with a red interior, or on which adults or their remains were found, was regarded as an occupied locality. As there are no other *Cerambyx* spp. of comparable size in Poland, potential mistakes in the recognition were minimised. Other large cerambycid species like *Ergaster faber* (L., 1761) are monophagous on Scotch pine *Pinus silvestris* L., 1753.

The species records were located in the field using a hand-held GPS and then converted into the ESRI shape-file format for later use. The occupied trees were determined at the species level. Each locality was classified into one of the five adopted habitat categories: forests, roadside trees, parks, solitary trees and other. The term 'solitary trees' means a single tree situated away from dense tree stands as well as trees loosely distributed in the agricultural landscape. In the case of forest localities, those within

the management of the State Forests were distinguished, in the case of roadside trees – those located on flood banks. Besides, all the localities were grouped according to their territorial-administrative appurtenance (municipalities, forest districts) and location within protected areas. In the last case, three forms of protection were considered: nature reserves, landscape parks and Natura 2000 (SACs).

Data analysis

To estimate the current and potential distribution of *Cerambyx cerdo* L., 1758 in south-western Poland, the kernel density estimation and the ecological niche modelling were used.

Kernel density estimation. – the kernel density estimation (KDE) in the Geospatial Modelling Environment (GME) programme (Beyer 2012) was used to assess the current spatial distribution of the species. The KDE is a non-parametric method that is used to estimate the probability density function of a random variable, with no specific assumptions about the underlying distribution shape. It was also used previously to characterise the distribution and abundance of species across space (Martins et al. 2013) and delineation conservation areas (O'Brien et al. 2012; Denoël and Ficetola 2015). A Gaussian kernel density function was selected and the optimal bandwidth was estimated using a plug-in method (Wand and Jones 1994), implemented from '*ks*' package in R (Duong 2007). Ten KDE values were considered from 10% to 95%, each of which corresponds to the smallest area protecting 10-95% of the species locations. For KDE calculations, a grid size of 0.01 km^2 (100 x 100 m cell) was used. The 95% KDE contours were used to present the overall current species distribution range in the region.

Ecological niche modelling. – To predict suitable habitats for *C. cerdo* L., 1758 in the study region, the ecological niche model (ENM) was developed, using the maximum entropy algorithm implemented in MaxEnt, version 3.4.0. (Phillips et al. 2017a, 2017b). MaxEnt software uses presence-only data to predict the distribution of the species by finding the probability distribution of maximum entropy, subject to a set of constraints that represent the incomplete information about the target distribution (Phillips et al. 2006). The result is a 'suitability map' depicting the probability of occurrence of the species at each raster cell of the area covered.

To eliminate redundant or spatially auto-correlated occurrence points, the *spatially rarefied occurrence data* tool in the SDMToolbox in ArcMap (Brown 2014) was used, thus reducing the occurrence localities to a single point within the distance of 1 km. Finally, in the model, 161 localities out of the total 1025 species' occurrences were used.

As environmental variables, 19 bioclimatic layers and an altitude layer from WorldClim (http://www.worldclim.org, Hijmans et al. 2005) and 6 layers related to forest fragmentation and availability of suitable *Quercus*-dominated forest patches were initially selected. Forest fragmentation layers were created based on the raster of Morphological Spatial Pattern Analysis of forest cover map, downloaded as a file MSPA 2006 from http://forest.jrc.ec.europa.eu/download/data/forest-data-download/. MSPA operates in raster images at the pixel level, where the input map is a binary representation of

a landscape coded as foreground (habitat patches) or background (non-habitat patches) (Vogt et al. 2007). The source raster (with a 25 m spatial resolution) was converted into a polygon shapefile and then four separate vector layers with the following MSPA classes were created: 'core forests' (interior area of forest patch excluding forest edges), 'islet forests' (patches too small to contain core forest), 'edge forest' (edges at the outside of forest patches) and 'perforated forest' (edges along openings inside larger forest patches). (For a detailed description see: Soille and Vogt 2009). The edge width was 25 m. As the next step, the percentage of the each MSPA class in each grid of the final raster was calculated with a spatial resolution of 30 arc second (0.93 x 0.93 = 0.86 km^2 at the equator). The last two environmental variables, the percentage and maximal age of *Quercus*-dominated forest patches, were based on forestry maps (available at: https://www.bdl.lasy.gov.pl/portal/). Subsequently, the pairwise correlations were checked amongst all environmental variables using SDMToolbox (Brown 2014) and factors with Pearson correlation coefficient values exceeding 0.7 (Dormann et al. 2013) were removed. Due to the high correlation between many variables (Suppl. material 1), 10 environmental variables for the MaxEnt analysis (see Table 1) were finally used.

The model in MaxEnt was built using 50 bootstrap replicate runs with the 'random seed' option. The records were split into 75% for training and 25% for testing for bootstrap replications. To facilitate model convergence, the maximum iterations were increased to 1,000. A jackknife test was then performed with all data to estimate the weight of each environmental variable in the model. The complementary log-log (cloglog) output was used with habitat suitability on a scale of 0-1, with higher values representing more favourable conditions for the species occurrence. The jackknife tests of variable importance were also used to identify those with important individual effects.

The final model was the average of all runs. To evaluate the performance of the final model, the mean area under the curve (AUC) was used for the receiver operating characteristic curve, calculated from 50 bootstrap models. The AUC ranges from 0 to 1, where a score of 1 indicates perfect discrimination, a score of 0.5 implies predictive discrimination that is no better than a random guess and values <0.5 indicate performance worse than random (Elith et al. 2006).

To distinguish between suitable and unsuitable habitat, the 10th percentile training presence (10%TP) threshold was applied. This threshold predicts unsuitable habitat for 10% of the most extreme occurrence records, as these may represent recording errors, ephemeral populations, migrants or the presence of unusual microclimatic conditions within a cell (e.g. Morueta-Holme et al. 2010). A high suitability of grid cell of output map was assumed if it showed presence probability higher than 0.632. Such predicted probability could be called a "typical" location of the species and corresponding to the predicted probability of occurrence of 0.5 for such a location in MaxEnt's logistic output (Phillips et al. 2017a). Finally, the suitability of habitat was categorised, based on the following classification: optimal ≥ 0.632, 0.632 < moderate ≥ 10%TP, unsuitable < 10%TP.

To assess of efficacy of the protected areas for the conservation of *Cerambyx cerdo* L., 1758 in the region, the contribution of each form of protected areas (PAs) was included to the protection of the known localities, as well as predicting habitats in

Table 1. The environmental variables used in ecological niche modelling of *Cerambyx cerdo* L., 1758 in south-western Poland.

Name	Description [unit]	Range	Mean ± S.D.	Data source
bio10	Mean Temperature of Warmest Quarter [°C*10]	140 – 182	174.2 ± 3.6	Worldclim (www.worldclim.org)
bio11	Mean Temperature of Coldest Quarter [°C*10]	- 35 – -8	-16.3 ± 4.6	Worldclim (www.worldclim.org)
bio12	Annual Precipitation [mm]	527 – 711	554.4 ± 13.1	Worldclim (www.worldclim.org)
bio19	Precipitation in Coldest Quarter [mm]	78 – 114	87.6 ± 5.2	Worldclim (www.worldclim.org)
Quercus	*Quercus*-dominated forests* [%]	0–95	3.8 ± 9.8	Forest Data Bank (https://www.bdl.lasy.gov.pl/portal/)
Quercus age	Maximum age of the *Quercus*-dominated forests* [years]	0–235	34.6 ± 55.1	Forest Data Bank (https://www.bdl.lasy.gov.pl/portal/)
core	Interior area of forest patch excluding forest perimeter [%]	0–100	17.9 ± 28.3	MSPA Pattern Maps (http://forest.jrc.ec.europa.eu)
edge	Edges – Outside perimeter of forest [%]	0-24	3.2 ± 4.1	MSPA Pattern Maps (http://forest.jrc.ec.europa.eu)
islet	Forest islets – disjointed forest patch and too small to contain core [%]	0-19	0.7 ± 1.3	MSPA Pattern Maps (http://forest.jrc.ec.europa.eu)
perf	Perforation – Inside perimeter of forest site [%]	0-25	0.9 ± 2.5	MSPA Pattern Maps (http://forest.jrc.ec.europa.eu)

* only forest stands with domination of native oaks, *Quercus robur* L., 1753 and *Q. petraea*, (Matt., 1784) were included.

the region. In addition, to assess the independent impact of the establishment of the Natura 2000 network on the species' protection, the proportion of the regional network of national protected areas (NPAs) was compared, such as nature reserves and landscape parks alone, in the current network of overall protected areas (OPAs), including Natura 2000 SACs. In the analysis of the contribution to the conservation of the species' habitats, an assessment was included for both predicted habitats in the whole study region and within the area of probable occurrence of *C. cerdo* L., 1758, delineated by the isopleth of 95% KDE.

Results

Current distribution and ecological preferences

In total, information was gathered from 1025 localities of *C. cerdo* L., 1758 in Lower Silesia; a decided majority (91.4%) were single trees, the remaining cases being groups of 2 to 7 occupied trees. In 67 localities (6.5%), the number of inhabited trees was unknown. All the records came from the pedunculate oak *Quercus robur* L., 1753. Despite the presence of other oak species in the environs of the localities (native *Q. petraea* (Matt., 1784) or introduced *Q. rubra* L., 1753 and *Q. cerris* L., 1753), no cases of other oaks being inhabited by *C. cerdo* L., 1758 were found.

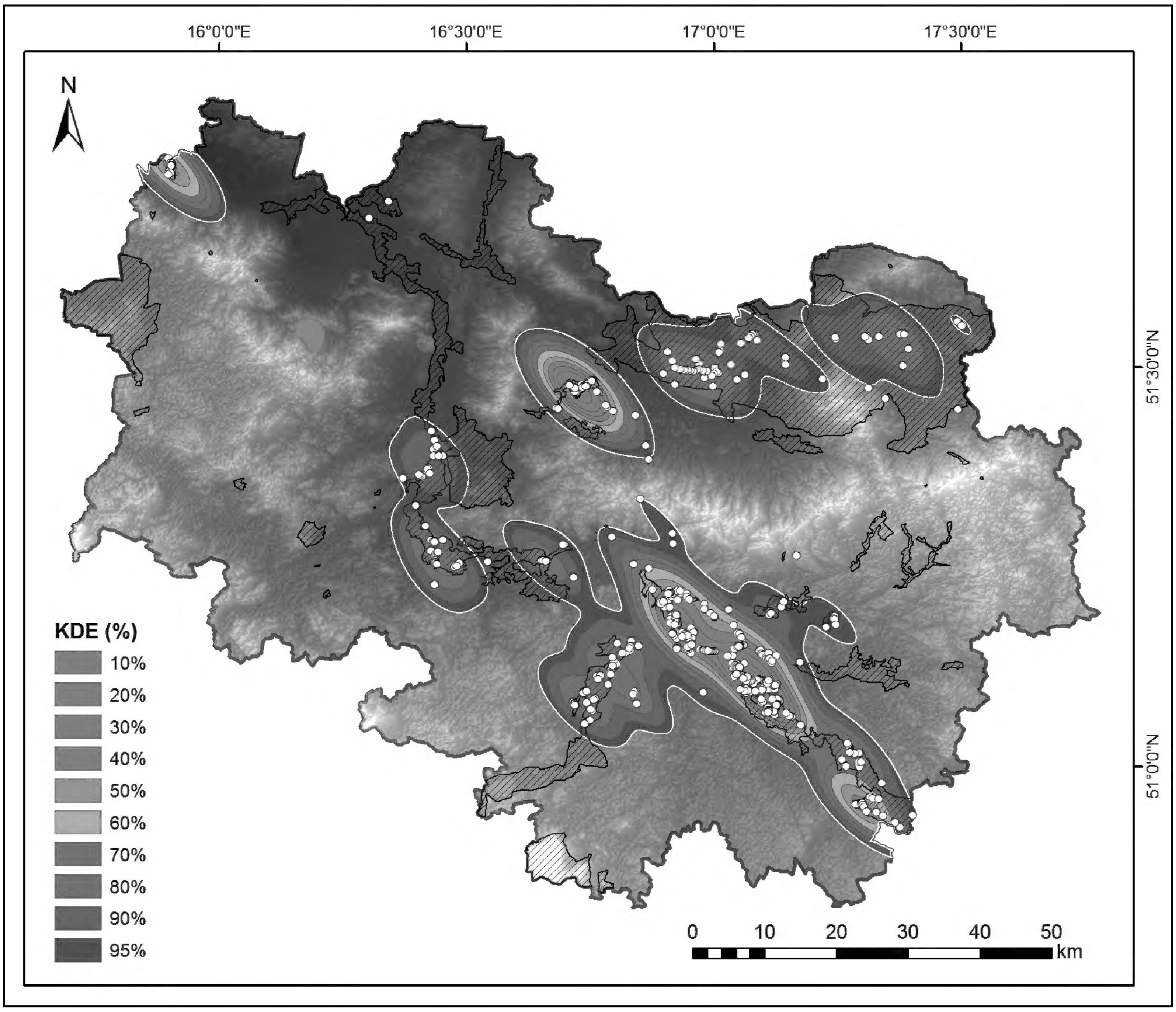

Figure 2. The current distribution of *Cerambyx cerdo* L., 1758 (n = 1025 locations) in south-western Poland and predicted species range delineated by kernel density estimations (KDE) using plug-in bandwidth selection. White lines show the border of 95% KDE. The dashed areas represent the network of overall protected areas (OPAs).

The occurrence of the great capricorn beetle in the study region was limited mainly to its eastern part, with a marked concentration in the valleys of the rivers Odra, Barycz and Bystrzyca (Fig. 2).

The KDE analysis also showed the high concentration of the occupied trees in the north-western part of the region, clearly isolated from the above-mentioned main populations of *C. cerdo* L., 1758 (Fig. 2). Overall, 95% KDE covered an area of 2,015 km^2, i.e. 21% of the study area. However 50% of the known localities (50% KDE) occurred in an area of just 270 km^2 which accounts for 2.8% of the study area.

The species' occurrence in the region, delineated by the isopleth of 95% KDE, largely coincides with the distribution of the highly suitable habitats predicted by MaxEnt modelling (Fig. 3). The model showed excellent predictive performance, with average training AUC for the replicate runs of 0.915 (SD = 0.011). The uncertainty of the prediction, expressed by the standard deviation of the 50 fitted models, showed a small increase in uncertainty especially in the south-eastern and north-western parts of

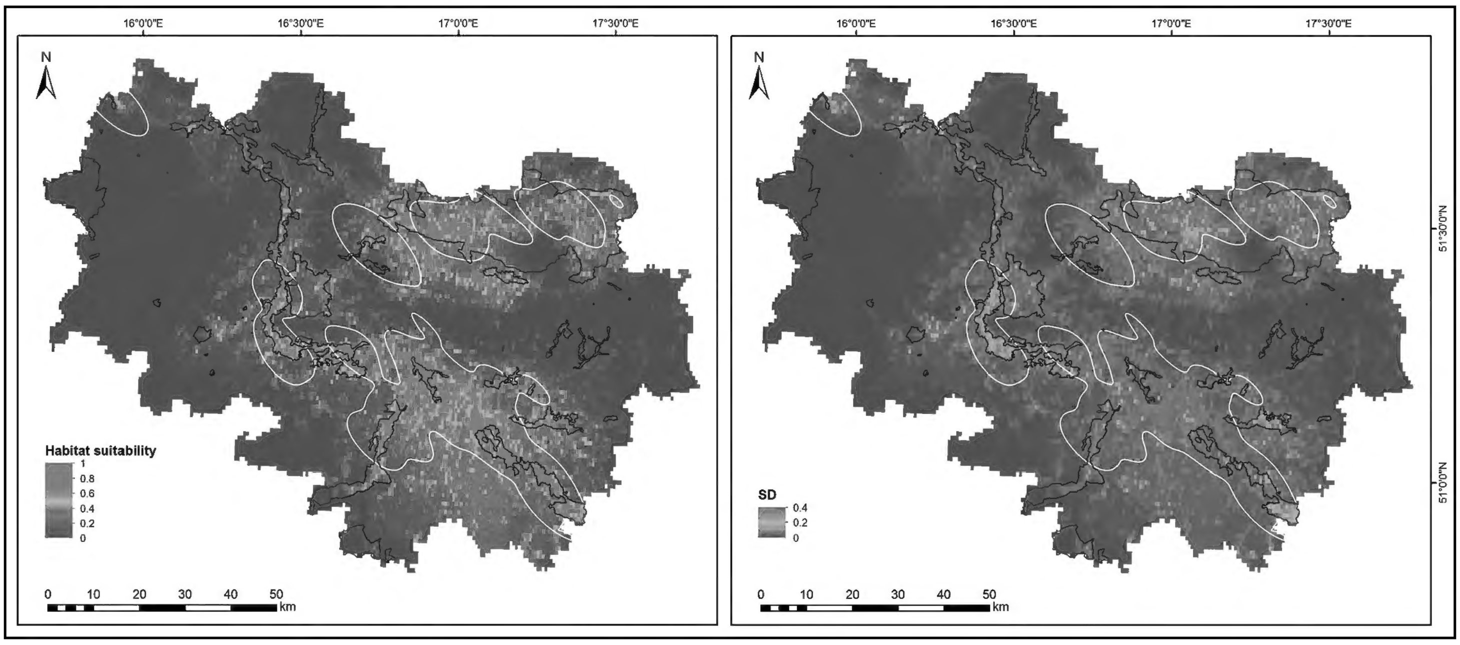

Figure 3. Averaged habitat suitability map for *Cerambyx cerdo* L., 1758 in south-western Poland (right) and standard deviations of predicted probabilities of occurrence (left) from MaxEnt models. Black-bordered areas show the network of existing protected areas (OPAs), white-bordered show the 95% kernel density isopleth.

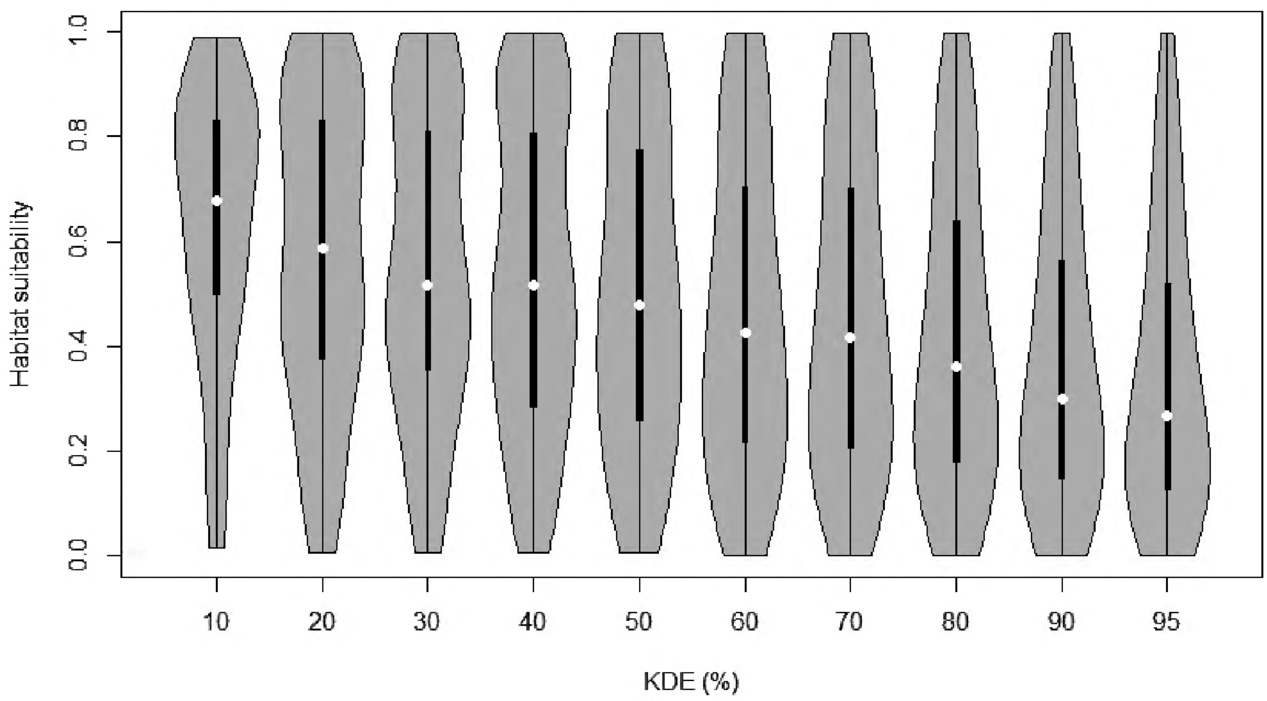

Figure 4. Violin plots of the habitat suitability within the 10 areas delineated by kernel density estimations (KDE) for *Cerambyx cerdo* L., 1758 in SW Poland. White dots indicate medians, box edges represent the inter-quartile range and the grey region and curve show the probability density function.

the study area as well as in the southern parts of SAC Łęgi Odrzańskie (Fig. 3). Based on the 10th percentile of training presence cloglog threshold (value of 0.2039), suitable habitats cover 23.9% of the surveyed area (2,288 km^2) and optimal habitats (threshold value of 0.632) cover only 5.2% of its area (502 km^2). Fifty four percent (54%) of the total area of suitable habitats and as much as 74% of optimal habitats were within the 95% KDE (1,241 km^2 and 383 km^2, respectively). The predicted habitat suitability decreased with a decreasing KDE value (Fig. 4).

Table 2. The relative contributions and permutation importance of the environmental variables to the MaxEnt model. Values shown are averages over replicate runs.

Variable	Percent contribution	Permutation importance
bio11	27.2	43.8
bio19	16.6	18.4
Quercus age	12.7	4.3
Quercus	11.4	2.2
bio12	10.3	8.8
edge	9.3	7.7
islet	6.5	2.5
bio10	3.2	7.5
core	2.0	1.9
perf	0.9	1.8

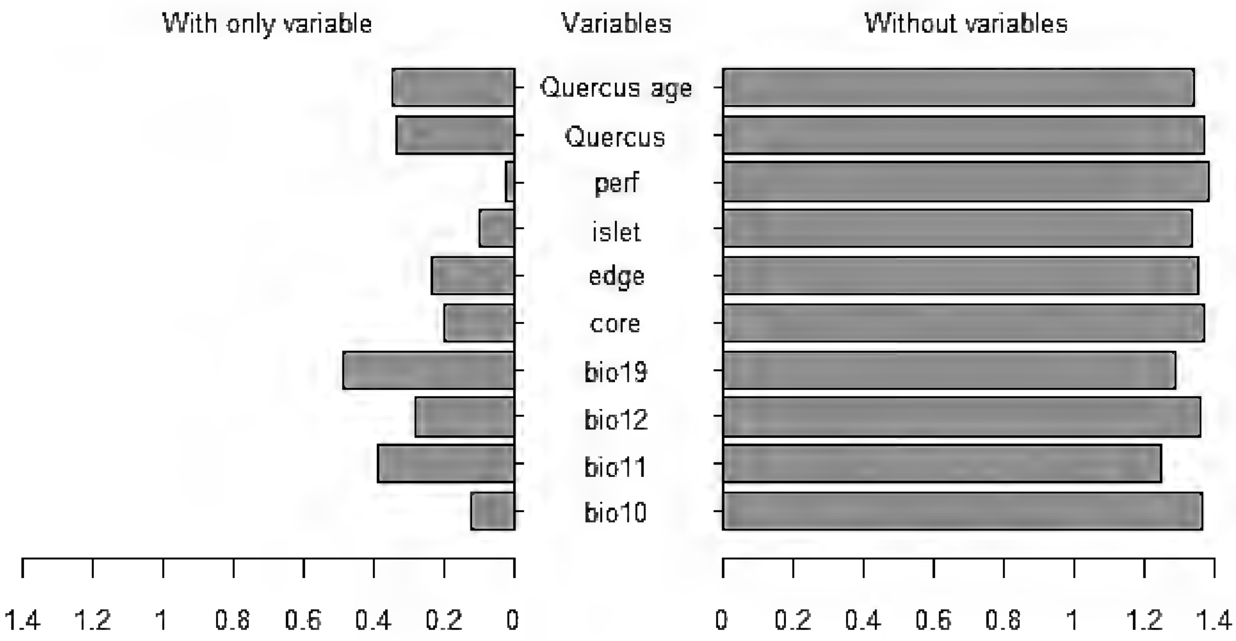

Figure 5. Results of jackknife test of variable importance using training gain. Values shown are averages over 50 replicate runs for each predictor variable alone (left) and the drop in training gain when the variables are removed from the full model (right). Explanation of variable codes: see Table 1.

Seven variables made more than 5% contribution to the MaxEnt model (Table 2). The jackknife test showed that the environmental variable with the highest gain, when used as the only variable, was the precipitation in the coldest quarter (bio 19), which appeared to convey the most useful information by itself. On the other hand, the predictor with the most information not present in other variables was the mean temperature of the coldest quarter (bio 11) which most reduced the gain when it was omitted (Fig. 5). In addition, some landscape variables, such as the percentage of oak stands, forest edges or forest islets as well as the age of *Quercus*-dominated forest stands, might also influence the species' distribution. Although the probability of the species' occurrence generally increased with increasing temperature and decreasing precipitation, extreme values appear to be avoided (Fig. 6). The probability of occurrence was also higher in places with old-growth *Quercus*-dominated forest stands, with a higher pro-

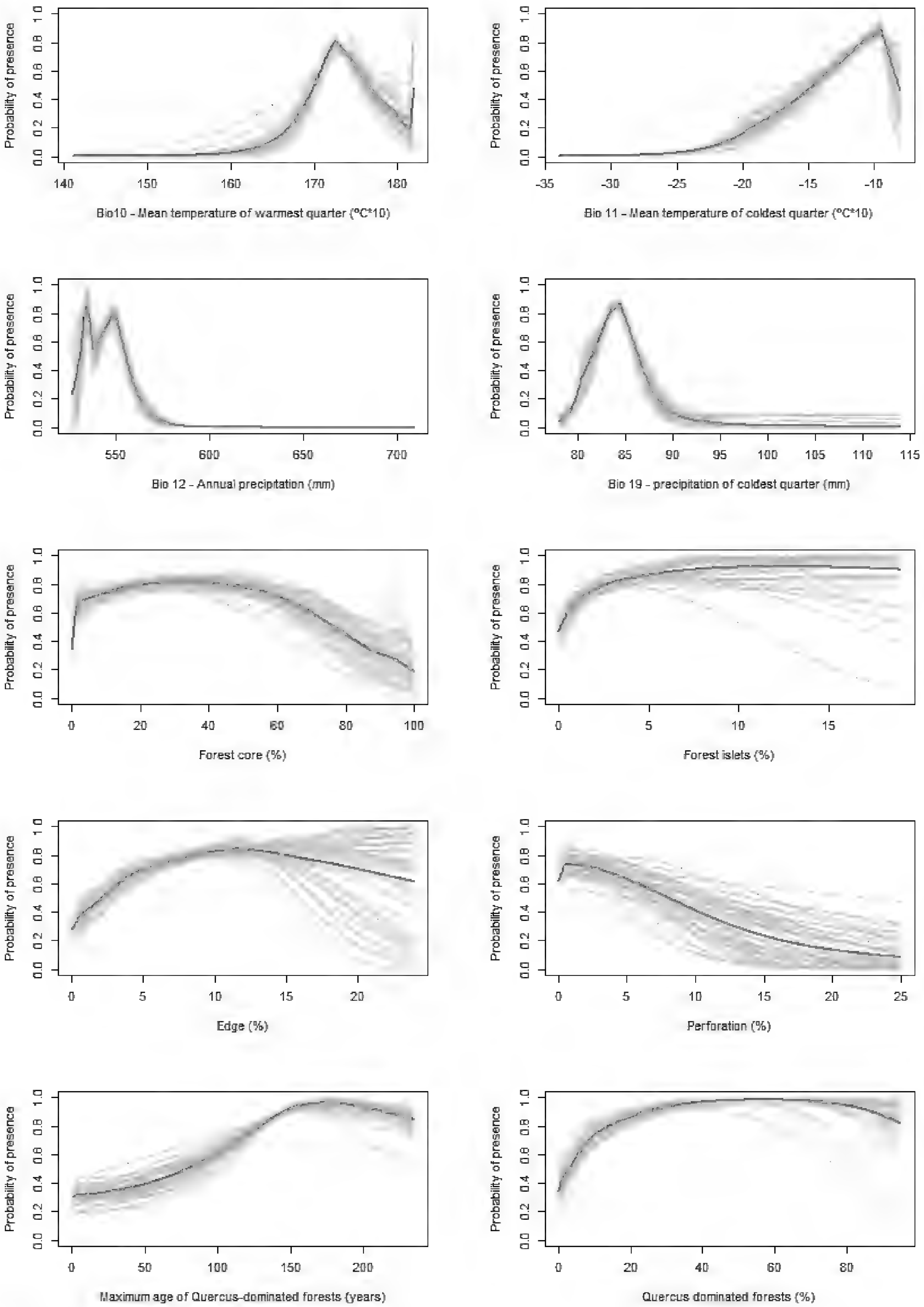

Figure 6. Response of *Cerambyx cerdo* L., 1758 (cloglog distribution of occurrence probability) to environmental variables used in ecological niche modelling with MaxEnt. Response curves for all 50 bootstrap models are shown with the mean curve in red.

portion of native oak species in the stands. However, it also decreased with the highest values. The response curves also show that the probability of the presence of the species increased with the decline in the proportion of forest interior (core) and the increase in the area of forest edge and forest islets.

Species distribution and protected areas

Although a considerable part of the localities of *C. cerdo* L., 1758 in the study region (74.2%) occurred within protected areas (PAs), the participation of each group of PAs in the species conservation was different (Table 3). Taking into account the surface area of the predicted habitats, Natura 2000 SACs are the most important group of PAs, covering more than 30% of the predicted area of suitable habitats in the region and more than 45% of optimal habitats (Table 3). Establishing the Natura 2000 network has increased the number of protected localities of *C. cerdo* L., 1758 from 129 to 730 (12.6% and 71.2% of the known localities in the study region, respectively) and has also significantly increased the area of suitable habitats of the species under protection. In particular, the area of the optimal habitats covered by PAs has grown considerably, increasing by more than twice (Fig. 7).

Most (69.2%) of the 295 known localities of the species outside the protected areas were located in urban areas. In total, 384 localities of *C. cerdo* L., 1758 were found within the cities, most of them (n = 356) being in the city of Wrocław. Forty three percent (43%) of the urban localities of the species (n = 165) in the study region are protected within the regional network of protected areas (OPAs), while those unprotected are mainly concentrated in the city of Wrocław (n = 207). Wrocław also brings together 17.1% of the area of suitable habitats and 29% of the optimal habitats of the species in the region outside the protected area network. For the probable area of the species' occurrence (95% KDE), these values are 32.8% and 40.2%, respectively. Wrocław, together with the regional protected areas (OPAs), encompasses more than 91% of the known localities of the species and more than 62% of its optimal habitats in the study region.

Table 3. Effectiveness of the systems of protected areas (PAs) in protecting *Cerambyx cerdo* L., 1758 in south-western Poland.

	Landscape parks (1014.5 km²)	**Nature reserves (80.8 km²)**	**Natura 2000 SACs (1213.2 km²)**
Number (percentage) of localities of *C. cerdo* in PAs	101 (9.9%)	43 (4.2%)	725 (70.7%)
Area (percentage) of predicted suitable habitats in PAs	465.7 km² (20.4%)	46.9 km² (2.0%)	712.0 km² (31.1%)
Area (percentage) of predicted optimal habitats in PAs	110.8 km² (22.1%)	8.9 km² (1.8%)	226.6 km² (45.1%)
Area (percentage) of predicted suitable habitats in PAs within 95% KDE	301.3 km² (24.3%)	44.2 km² (3.6%)	466.9 km² (37.6%)
Area (percentage) of predicted optimal habitats in PAs within 95% KDE	87.9 km² (22.9%)	8.9 km² (2.3%)	185.6 km² (48.4%)

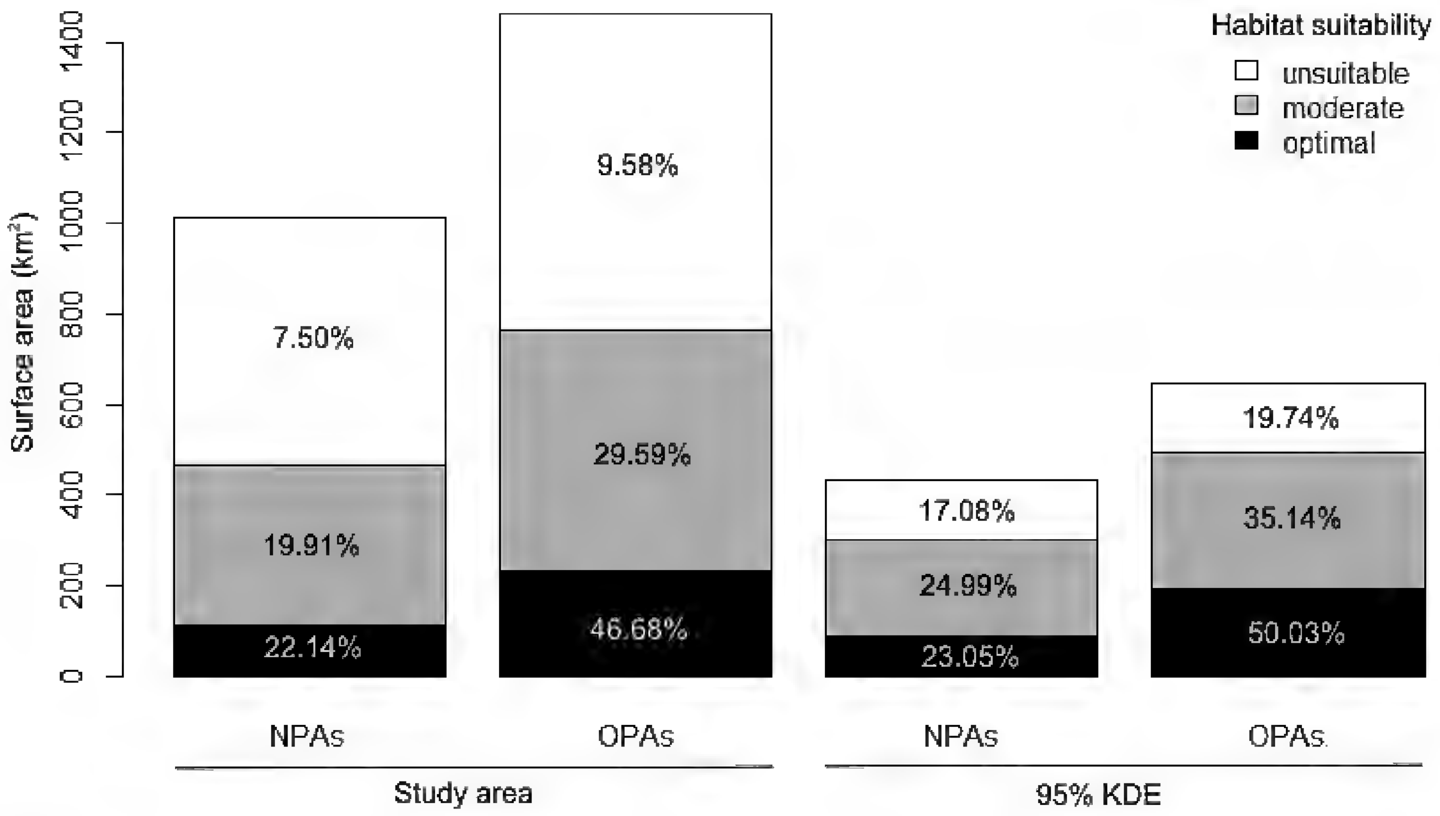

Figure 7. Surface areas (km^2) obtained by ENM (MaxEnt) within the study region and the 95% kernel density isopleth for *Cerambyx cerdo* L., 1758 for three different suitabilities covered by national protected areas (NPAs: nature reserves + landscape parks) and overall protected areas (OPAs: NPAs + Natura 200 SACs). Percentages represent the percentage of the total area of the habitat type within the study region and the 95% KDE. Suitability thresholds: optimal ≥ 0.632, 0.632 < moderate ≥ 0.2039, unsuitable < 0.2039.

Discussion

More than a thousand localities of *C. cerdo* L., 1758 were recorded confirming that the studied region held numerous localities of the species which is declining in many countries in Central Europe within its north and central range distribution. The fragmentary character of historic data makes it difficult to say with certainty if the results show a satisfactory state of the species' conservation or only a better knowledge of its distribution (Burakowski et al. 1990, Starzyk 2004). Considering the lack of distributional data from the westernmost part of the region, the Silesian-Łużyce Lowland, despite the historic records and the presence of trees with signs of previous occupation (Starzyk 2004), probably the latter is true. Similarly, the complete absence of the great capricorn beetle in the southern part of the region, in the belt of Sudetic foothills and basins, despite historic records of its presence (Burakowski et al. 1990, Starzyk 2004) and the records from lower mountain altitudes in Europe (Sláma 1998), seems to confirm the observed decline of *C. cerdo* L., 1758 in the region. As in other populations from the northern and central parts of the continent, the pedunculate oak proved to be the only host tree for the larvae (Buse et al. 2007, Albert et al. 2012). At present, there is no satisfactory explanation for this monophagy, especially considering the availability of large trees of other species, including native and alien members of the genus *Quercus*, for example the northern red oak *Q. rubra* L., 1753. This North American species was

quite common within the studied area and many of its individuals have achieved a significant size compared to infested specimens of *Q. robur* L., 1753. Recently Oleksa and Klejdysz (2017) hypothesised that differences in the structure of the bark (deeply fissured in *robur*, smooth in *rubra*) and in physicochemical characteristics of the wood and phloem may play important roles in host selection and avoidance of the latter by *C. cerdo* L., 1758.

The results of ENM confirmed the thermophilous character of the species. These results also suggested that there is a relatively higher probability of finding *C. cerdo* L., 1758 in areas with older oak stands, although a negative impact of core forest areas and positive effect on the percentage of forest edges indicates the avoidance of the forest's interior.

The concentration of records of *C. cerdo* L., 1758 in the valleys of the rivers Odra, Bystrzyca and Barycz, besides the favourable thermal conditions compared to the adjacent areas, can also be explained by the presence of relatively numerous deciduous forests, including some with a high proportion of oak, which have been preserved because of the little use of those areas for intensive agriculture and because of planting oak on dykes of fish ponds as in the Barycz valley. Furthermore, the character of such tree stands, in the form of smaller or larger forest islands or rows, seems to suit the species' requirements. It is noteworthy that the trees in such stands grow far apart, thus enabling a faster growth in thickness and in turn results in thicker bark, both of those parameters being very important for the species (Buse et al. 2007, Albert et al. 2012, Oleksa and Klejdysz 2017). The preference for trees of larger diameter may result both from the large size of the larvae and thus greater food requirements and from the large sun-exposed areas of larger trees. The latter is also closely associated with the situation of the host trees in the landscape; this model and other studies show that, in this case, it is the so-called openness of habitat that is important. In the conditions of Central Europe, a longer feeding period for the larvae may be crucial for completion of the life cycle and maintaining viable populations.

Despite the passing of more than 20 years since the launch of the System Natura 2000, it still causes great controversies in Poland and in other countries of the European Union (Maiorano et al. 2007, 2015, Verovnik et al. 2011, Albuquerque et al. 2013, D'Amen et al. 2013, Hochkirch et al. 2013, Lisón et al. 2013). Paradoxically, the most criticised aspect is the establishment of the areas based on scientific criteria, i.e. the objective value of the area for given habitats and species (listed in the Annexes of the Habitats Directive), without giving priority to consideration of spatial management plans, forest management plans or opinions of local communities (e.g. Charbonneau 1997, Krott 2000, Weber and Christophersen 2002, Paloniemi and Tikka 2008, Zehetmair et al. 2015). Some of the opponents of the system also identify the threat to the development of regional and local communities (Krott 2000, Eben 2007, Makomaska-Juchiewicz 2007).

In the case of invertebrates, including insects, the species lists in Annexes II and IV of the Habitats Directive have also been criticised (Hochkirch et al. 2013). There is no doubt that the critics are right in their views that the lists are dominated by representatives of a few orders, especially butterflies and beetles which are mainly represented by

spectacular and charismatic species (Cardoso 2012). Such critique however disregards the fact that, besides the social awareness which is certainly important, such species are often very important for the preservation of macro- and microhabitats. It should be mentioned that, preserving the population of the great capricorn beetle in good condition, may be of significance for other organisms. The beetle is virtually the only species in this part of Europe which fully deserves the name of environmental engineer and umbrella species. As shown by the studies in northern Germany (Buse et al. 2008) on the fauna of saproxylic beetles associated with the pedunculate oak, the number of species is significantly higher in oaks occupied by the great capricorn beetle. Furthermore, endangered species, according to the relevant red lists, are more abundant in oaks occupied by the beetle. As many as 33 species, 31 of them from the German red list, were recorded only in such trees (Buse et al. 2008). Additionally in the study region, an array of beetle species were recorded, some of them very rare, for example *Lacon querceus* (Herb., 1784) or *Dermestoides sanguinicollis* (F., 1787), only in oaks occupied by the great capricorn beetle (Smolis et al. 2016). Recent studies in Spain also showed that hollows in oaks occupied by the capricorn beetles, *Cerambyx welensii* Küst., 1846, had a greater species richness of beetles, compared to unoccupied trees (Micó et al. 2015). Protection of such species like *C. cerdo* L., 1758 not only makes it possible for the many accompanying saproxylic organisms to occur, but may also favour conservation of many rare and endangered taxa.

Another argument used by the opponents of Natura 2000 was that it doubled the forms of nature conservation which existed and functioned in all European countries, especially area and species protection. These results do not confirm this objection, but instead show how essential and effective a tool Natura 2000 is in conservation of species such as *C. cerdo* L., 1758. Within nature reserves and landscape parks which occupy 80.8 km^2 and 1014.5 km^2, 43 (4.2%) and 101 (9.9%) of the species' localities, respectively were found. In the network Natura 2000, with its area of 1213.2 km^2, 725 localities (70.7%) were found. Great differences between the compared systems, in favour of Natura 2000, also pertain to the area (percentage) of predicted suitable habitats, area (percentage) of predicted optimal habitats, area (percentage) of predicted suitable habitats within the 95% KDE and the area (percentage) of predicted optimal habitats within the 95% KDE (Table 3). It should also be added that in 10 Natura 2000 areas in south-western Poland *C. cerdo* L., 1758 has significant populations and is regarded as a "target species" (Standard Data Forms, 2017). These results showed that, amongst the existing forms of protection, it is Natura 2000 (SACs) and the activities undertaken in such areas that will have the greatest effect on the preservation and effective protection of the capricorn beetle and its related biodiversity. As suggested by data from other countries, the capricorn example is not an exception in the context of insect protection in the decades to come (Jurc et al. 2008). It should be emphasised that a total of 1207 Sites of Community Importance (Natura 2000 sites) have been designated in the EU where the great capricorn beetle is recorded (http://ec.europa.eu). As shown

by Jurc et al. (2008) and Bosso et al. (2012), Natura 2000 areas are important for the preservation of rare and endangered beetle species. It is optimistic to note that most of the recorded localities and also predicted and suitable habitats of the species are, in theory, under legal protection resulting from their location within protected areas (Fig. 7).

The pessimistic aspect is associated with the possibility of preserving the species in urban areas, as the potential threat to public health from the beetle-occupied trees might result in fallen branches (Carpaneto et al. 2010) which are often partially dead or dying. In the studied region, nearly 40% of the localities were situated in densely populated areas which even now causes conflict between beetle protection and the safety of citizens. The concentration of localities in the above areas results from the species' climate and habitat preferences: it chooses the warmer microclimate of cities and selects large and rather exposed pedunculate oaks (Strojny 1985, Sláma 1998, Buse et al. 2007, Albert et al. 2012) which are abundant in urban areas (parks, roadside tree rows), where the trees are not removed once they exceed the so-called felling age and most often live to be ancient.

On the other hand, the occurrence of the species "close to humans" offers a unique opportunity to educate the society in matters of protection of saproxylic organisms; as a result of its size and interesting biology, the great capricorn beetle is an ideal candidate for an educational subject.

Conclusions

The results not only supplement and update the distributional information on the great capricorn beetle in south-western Poland, but they may also contribute to devising an effective strategy for conservation of this endangered species. The presented data clearly suggest that such a strategy would require the cooperation of many authorities: local governments and forest management institutions such as State Forests, City Green Management (with their communal forests and city parks), water management authorities (floodplains and flood banks) and roads management. The results point to a particular responsibility for the authorities of the largest city within the region Wrocław which holds more than 30% of the localities. Additionally, the largest owner and manager of the forests in Poland, the State Forests, should take an active part in formulating and improving such a strategy.

This study confirms that modelling distributions of the saproxylic species can provide an objective means for the identification of potentially optimal and suitable habitats for their conservation. The analyses on protected area efficacy showed that existing national networks of conservation areas alone are not adequate for preserving species such as *C. cerdo* L., 1758. Thus, Natura 2000 is the cornerstone on which protection strategies should be built. However, adaptive management plans need to be compiled and then implemented both in each area and their surroundings.

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Supplementary material 1

Table S1. Correlation matrix of all initial environmental layers selected for modelling in MaxEnt

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Data type: statistical data

Link: https://doi.org/10.3897/natureconservation.19.11838.suppl1

Supplementary material 2

Distribution data of *Cerambyx cerdo*

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Data type: occurence

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